REMARKS BY DR. G. WAYNE CLOUGH

"The Future of Technology"

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(SLIDE #1: TITLE) It is an honor to be invited to share a few thoughts on the future of technology at this Executive Forum. Given the rapid pace of development of new technology and the growing challenges society faces, this is a very timely topic and one that needs the thoughtful attention of all of us. Only yesterday I was at MIT speaking to a conference on a similar topic. Everywhere people are striving to understand what the future might look like, but the pace of change and the vast potential of many new developments makes this a difficult task.

Tonight, I speak from the perspective of a person who is daily immersed in technology, one who leads an institution that graduates the largest numbers of engineers in the nation, and a civil engineer who is concerned about longer term issues that will affect all of our lives and that need our attention.

Today's world is driven by technology. The marvelous "new economy" is thriving on because of developments in technology, and it is hot. Developments in

biotechnology, information technology and advanced communications are making money hand over fist. Yet, the innovations that allowed us to reach this point in our life are nothing compared to what is to come, assuming that we continue to invest in the necessary research and development.

(SLIDE #2: NANOTECH) For example, new developments in the field called nanotechnology are now allowing us to engineer molecules, something only imagined 20 years ago. "Nano" means the same thing in the world of science as it did on the old "Mork and Mindy" TV show – very tiny. A nanometer is one billionth of a meter and is the scale used to measure molecular distances. At this level, nature long ago mastered capabilities we are only beginning to understand. Plant leaves contain a magnificent energy device called a chloroplast, which carries out photosynthesis using molecular machines called thylakoid disks that convert light and carbon dioxide into biochemical energy. Soon we too will be able to do this in a lab, and the implications for us are tremendous.

Nanotechnology has the potential to change the world as we know it. Imagine superconductivity without the need for temperatures of minus 400 degrees, or films that allow materials to change behavior depending on the environment, or the ability to store all of mankind's written knowledge on a device the size of a

pinhead, or miniature implants that replace nerve functions in the body, or molecular sized computers that are more powerful than any we have ever known. All of this has implications for our lives and can make them better. Yet, as I will show later we will need all of the technology we can get if we are going to maintain the quality of the lives we now live.

Georgia Tech has already invested heavily in the nanotechnology field. We have attracted some of the world's best faculty and are planning a remarkable new building for them as part of a new $140 million complex of facilities to the east of Atlantic Street and north of Ferst Drive. Beyond what nanotechnology can do to solve technical problems, there are, of course, significant ecomomic development ramifications to what will come. We want to insure that Atlanta and Georgia are positioned to benefit.

Our investments to date are timely since NSF has recognized the power of this technology and is going to invest hundreds of millions of dollars in it in the coming decade. We are readying ourselves to win the coming intense competition because this is where the future lies.

For all we understand about the potential of developments like nanotechnology, it is still hard to predict exactly what might happen and when. And before this brave new world arrives, we need to be doing a lot of thinking.

(SLIDE #3: 3 QUOTES) It is always dangerous to talk about the future of anything. Despite the fact that the future is arriving around us every second, we still cannot see it clearly. Even those who participated in creating each successive generation of computers could not see beyond the innovation of the moment with any degree of accuracy. These men were leaders and experts in their field, and they still got it wrong, which leads one to undertake predictions about the future with a degree of humility and an appreciation for the difficulty of the challenge.

(SLIDE #4: TITLE: THE GATHERING STORM)

Yet there are some matters related to the future of technology to which we can speak with clarity. I'd like to talk about two of these realities this evening. First, our society is enamored of new technology in computing, communications and biotechnology, but we have a blind spot when it comes to the basics society needs for its very life and breath. As a result, we are facing growing problems with our infrastructure, environment, and exposure to natural hazards – problems that will come home to roost early in this new century.

(SLIDE #5: POPULATION GRAPH) By the calculations of the United Nations, the population of the world reached 6 billion last October 12th. It took all of world history up until the early part of the 1800s to reach the 1 billion mark. The second billion took nearly a century. The most recent billion was accomplished in about 12 years. Fortunately the birth rate around the world is beginning to slow, and the UN hopes that the world population will peak at 10 billion sometime during the latter part of the next century, then begin to decline.

However, the question remains of how to accommodate an additional four billion people in the next 50 years. And it will be an aging population with an added lifespan of 30 to 40 years common by the year 2050. Yesterday's approaches and technologies for housing, transportation, water and energy supply, air quality, response to natural disasters, and land use are not likely to suffice for tomorrow's challenges.

(SLIDE #6: RIVERS RUN DRY) Consider the case of fresh water, with supplies being depleted faster than they are renewed. Water tables are falling in China, India and the United States, which together produce half of the world's food, and an increasing number of rivers are sucked dry before they ever reach the sea. By

the year 2025, 3 billion of the world's people will live in places where fresh water resources have fallen below sustainability levels.

(SLIDE #7: RIVER QUOTE) In the United States, Texas, Oklahoma, Kansas and Colorado have all lost irrigated land during the past two decades because of aquifer depletion. The Colorado River rarely has any water left by the time it reaches the Gulf of California. Here in the southeast, Georgia is deadlocked with Alabama and Florida over the Chattahoochee River. There are no easy answers to the challenge of providing an adequate water supply, and we cannot extrapolate what we have done in the past into the future.

(SLIDE #8: INFRASTRUCTURE) We have infrastructure problems as well as supply problems. The dowager of American cities, New York, has almost 6,200 miles of underground water pipes, and by 2030, more than half of them will be over 100 years old. They rupture 600 times every year, causing flooding and water cut-offs, and sometimes triggering street cave-ins and breaks in adjacent gas lines.

(SLIDE #9: DRINKING WATER) The Environmental Protection Agency estimates that America will need to spend $300 billion over the next 20 years to

upgrade its water systems, and because little is being done, it will get worse before it gets better.

The same is true of the 160,000 miles of oil pipelines that criss-cross this nation. Some of them are more than 90 years old, and for the past decade they have been leaking more oil each year than spilled from the Exxon Valdez off the coast of Alaska.

(SLIDE #10: GARBAGE GRAPH) Our society is famous for outdoing itself in waste production. Toronto, which used to claim it was "New York run by the Swiss," has a growing garbage problem. After years of closing landfills, Massachusetts announced last fall that it will allow six landfills to expand. Manhattan accumulates 28,000 tons of garbage every day – more than 10 million tons a year – with no place to put it. When Virginia recently discovered it was becoming New York's preferred dumping ground, it legislated against it even though Mayor Guliani told Virginians that they should consider New York's garbage their new gold mine. Georgia recently gained national notoriety by increasing our output of solid waste by 5% per person from 1997 to 1998.

(SLIDE #11: CAR) Americans are also notorious for vehicle travel, which produces gridlock and air pollution. While the U.S. population increased 30 percent over the past 30 years, the number of licensed vehicles increased 87 percent and the number of vehicle miles traveled increased 130 percent.

(SLIDE #12: ATLANTA) In addition to causing gridlock, motor vehicles also generate at least half of America's urban air pollution. Metro Atlanta tops the nation with an average one way commute of 34 miles. In response, government planning agencies have announced a $37 billion transportation program over 25 years to improve both mobility and air quality. Georgia Tech is presently conducting an innovative study that correlates land-use patterns with travel behavior, and it was commissioned not by city planners or transportation engineers, but by the National Centers for Disease Control. The environmental organization Second Nature claims that today more Americans die prematurely from air pollution than from traffic wrecks.

(SLIDE #13: AIRPORT) Commercial air travel is also growing rapidly. Last year saw 1.5 billion passengers worldwide, 650 million of them here in the United States, and both of those numbers will double in the next 15 years. Add to that the rapid growth in air freight operations caused by e-commerce.

(SLIDE #14: PLANE CRASH QUOTE) The Airports Council International says the United States needs $10 billion a year in new infrastructure to keep up. Atlanta, which already has one of the world's largest facilities, has announced a $2.5 billion investment program over the next five years.

(SLIDE #15: HURRICANE: NATURE'S REVENGE) Land-use patterns have not only snarled traffic and generated air pollution, they have also put more people and property at risk for natural disasters. The past several decades have seen a global population migration to marginal land that is at risk for natural hazards. When both the threat of damage to lifeline infrastructure and the speed of commerce are increasing simultaneously, the potential for economic losses from natural disasters expands significantly.

In 1998, worldwide damage from storms, floods, drought and fires reached $89 billion, three times what it was in 1997. Natural disasters killed 32,000 people and drove 300,000 from their homes, and much of the suffering and property loss was the result of humans building on high-risk terrain.

Here in the United States, more than a fourth of the population now lives within 50 miles of the coast with infrastructure investments of $2 trillion dollars in support of this movement of people. And this in face of the fact that the last five years have been the most active hurricane period of any five years in recorded history.

(SLIDE #16: STORM QUOTES) Although the experts are reluctant to blame the increasing frequency of hurricanes on global warming, there is little doubt that it has increased the severity of the storms. Last December, the chief meteorologists of Great Britain and the United States issued a rare joint statement indicating that the 90s were the hottest decade in the past 1,000 years, that global warming is now changing the world's climate rapidly, and that scientists can no longer explain the rapid pace of the warming without taking human activity into account.

Taken together, the effects of population growth, increasing transportation congestion, decaying infrastructure, shrinking waste management options, environmental deterioration, destruction from disasters, and impact of global warming represent a wave threatening to crest over our civilization.

(SLIDE #17: WOODY ALLEN) It is beginning to sound like Woody Allen's glass half-full assessment in *Side Effects*. His choices don't leave us with the warm and

fuzzy feelings we would like. If you want to be more academic, Woody's options sounds like Paul Ehrlich, the biology professor who has been making doom-and-gloom predictions since the 60's. But none of them have yet come true, and that, I would like to believe, is because he fails to take the inventiveness of engineers into account.

(SLIDE #18: SAFE HARBOR) Like Woody Allen, I believe the new millennium offers a crossroads. But I also believe that if we take action to prepare, we have the opportunity to meet our challenges with creativity. We need to build a safe harbor against the gathering storm, and that calls for us to forge a link between the needs of a growing world population and the emerging technology research and management paradigms. All of this can hopefully be done while maintaining a robust economy based on new technological developments.

(SLIDE #19: TITLE: TECH ANSWERS / INFRA SOLUTIONS)

That brings me to the second aspect we know about the future of technology, and that is the fields where technology is being produced. Much of the nation's research money is pouring into areas like biotechnology, nanotechnology, and information technology. Georgia Tech already conducts significant research in these three fields, and we are strengthening our potential for leadership with state-

of-the-art facilities. Our challenge is to view these fields in the bigger context of what society needs to survive and thrive, and use these emerging technologies responsibly and ethically as a springboard for broader human progress.

(SLIDE #20: BIO TECH) The 21st century has already been declared the age of biology. The medical improvements of the past century doubled the world's average life expectancy, but biomedical engineers assure us that was chickenfeed compared to what they will accomplish over the next hundred years. Researchers at Georgia Tech are testing artificial implants that the body will embrace and weave into its own structure. Genetic engineers are exploring ways to fix congenital defects and diseases. Our campus contains the only National Science Foundation Center for the Engineering of Living Tissues, where scientists are developing techniques to grow replacement tissues and even organs in the lab from a patient's own cells, helping the body in essence to restore itself.

(SLIDE #21: MICROBES) The impact of the age of biology is also being felt on environmental engineering. Bio-remediation to clean up waste was unheard of 40 years ago. Today, microbes represent the cheapest and most effective approach to cleaning up oil spills. For the future, biotechnology raises the possibility of

treating wastewater at the point of generation, which would significantly reduce the need for large-scale sewage infrastructure.

(SLIDE #22: CIRCUIT BOARD) Many of the biotechnology advances of the future will be achieved using new computing technologies that enable better modeling of the biological systems we want to improve. The key for future computing and advanced communications technology will lie in the convergence of hardware and software, or smart, preprogrammed devices and communications pipelines.

Georgia Tech leads a team that consists of MIT, Stanford, Cornell, and Rensselaer Polytechnic Institute in a $17 million project funded by DARPA and Sematech to design the next generation semiconductor. This work is beginning to explore new developments at the nanotechnology level and is a perfect compliment to the thrust of the Yamacraw Project, which is to educate a high-tech workforce. Our goal is to help Georgia become the nation's leader in the fundamentals underlying of all computing, communications and entertainment technology, and to produce the high level talent needed to fill the jobs that will come.

(SLIDE #23: VIRT REALITY) One of the most exciting developments on the horizon is the convergence of biotechnology and computing technology. Researchers at Georgia Tech are on the forefront of this remarkable development – the merging of silicon, bioengineering and bioscience to create mechanical devices that will mimic the nano machines nature has long used. We will be able to compute much like the human brain, using neural networks in ways that are destined not only to match human intelligence, but to change it. You may have seen the article in Sunday's Atlanta paper about "the evolution of e-man" and the merging of mind and machines. It included a picture of Georgia Tech's Bill Ditto, who has uses chaos theory and silicon stimulation of neural cells from leaches to create a functioning computer. We have also recently hired Professor Dick Lipton from Princeton who has found the means to use DNA as a computing device.

(SLIDE #24: BRAIN SCAN) Computer guru Ray Kurzweil recently published his predictions for the 21st century in a book called *The Age of Spiritual Machines: When Computers Exceed Human Intelligence*. He projects a virtual reality environment that uses nano-sized neural implants to intercept and intervene in the signals that pass between the brain and sense organs like eyes, ears, nose and skin. These devices will not only correct some sensory disabilities, they will also enable all humans to enter virtual environments without any other equipment than what is

in our heads. Imagine what that will do to the way all of us work with each other and carry out our professions!

(SLIDE #25: GLASS BLDG) We will also see the growing impact of computers on our environment. We now construct "smart" buildings in which the power, lighting, heating, air conditioning, security and fire protection systems can talk to each other, and they are about to get even smarter. We are on the cusp of an age when building security systems will routinely read voices, palm-prints or footprints rather than keys or keycards, and computers will automatically adjust the inside environment based on how many people are there, where they are in the building and what they are doing. To see how innovations like these could affect your own home, please visit our Aware House on Tenth Street when it opens in the near future.

(SLIDE #26: DOT CAMERA) Computers and communication technology are also at the heart of "intelligent transportation systems." And Georgia Tech helped develop a national prototype here in Atlanta for the Olympics. A variety of advanced sensing, computing and communications technologies handle tasks that range from collecting tolls to controlling traffic signals, and they are integrated into coordinated systems that manage traffic flow.

Last October, the Federal Communications Commission set aside 75 megahertz of spectrum for smart highway technologies. This "air space" is reserved for short-range, wireless links that allow transportation officials to communicate with vehicle drivers much like air traffic controllers now communicate with pilots.

(SLIDE #27: OPTICAL FIBERS) Within the past five years researchers have learned how to lace materials with optical fibers that contain strings of sensors. Data from the sensors passes along the fibers to an opto-electronic data processing unit. This has multiple applications ranging from weapons to building materials and even clothing. Georgia Tech recently gained national and international attention when researchers laced optical fibers through a shirt that can constantly monitor the vital signs of the wearer and pinpoint any intrusions such as an injury. This smart shirt technology has applications for hospitals, home health care, and sports. It can be worn by soldiers on the battlefield and infants at risk for SIDS. Look for it to soar onto the scene soon in the form of a commercial product.

(SLIDE #28: NEW MANAGEMENT STRATEGIES)

Realizing the incredible possibilities ahead in new technologies requires new management strategies to implement them. Today's most agile industries and

corporations have adopted techniques that utilize teaming, partnering, entrepreneurial skills and Internet communications. These approaches allow for the first true productivity increases in civil engineering and construction in 30 years. More is to come.

(SLIDE #20: NET WIRES) While Internet retail has attracted much of the attention, the real electronic revolution is expected to be in the way business works. Boston Consulting Group, Inc. expects business-to-business Internet transactions to total $2.8 trillion by 2003. In a recent survey of industrial buyers conducted by *Purchasing Magazine*, more than a third had already begun purchasing over the Internet, and most of the remaining two-thirds expected to start making Internet purchases within the next three years. At our recent e-commerce/logistics conference, companies as diverse as Home Depot and Ford Motor Company described the incredible productivity increases they expect as a result of e-commerce.

(SLIDE #30: BOEING 777) But the impact of the Internet on business and industry will reach beyond buying and selling to change the entire process of designing and manufacturing in fundamental ways. A good example is the Boeing 777 aircraft, which is one of the world's largest and most complex machines. Yet

was designed and built in record time using compatible software on computers that were networked across hundreds of companies in a dozen different nations. Like most e-business, this phenomenon is still in its infancy and is very fluid, but it's not a passing fad that will go away.

(SLIDE #31: WATER TREAT) Another consideration that is becoming more pervasive in the way society operates is sensitivity to the environment. We used to view development as something that of necessity happened at the expense of environmental preservation. But as the population grows and our resources dwindle by comparison, we are coming to realize that any approach that is adverse to environmental preservation and resource conservation will be a dead end. We can no longer measure benefits against financial costs alone, but also against environmental costs.

(SLIDE #32: DUNNE QUOTE) Most reasonable people today understand that it is as much in the true interest of business, as it is in the interest of the most ardent environmentalist to preserve this small planet for the future of all of its species. And Georgia Tech has established itself as a world leader in developing the sustainable technology and benign manufacturing processes that reconcile these interests, so that we do not inadvertently destroy the future in the process of trying

to create it. Our goal is that every student who graduates from Georgia Tech, not just a few, are imbued with the ethic of sustainability and its design principles.

What is particularly important is that sustainability will be the only way business can do business in the future. Already dozens of major industries have adopted sustainable technology as the way they will do business, and governments will soon make it law. Those who wait will not only have to pay for the delay, but they will miss out on the wave of business opportunities are already opening to those who recognize the potential.

There is no question that the coming century and millenium will bring unprecedented opportunity to the scientists and engineers who develop technology. But it will also bring unprecedented challenges for society and our technology.

(SLIDE #33: KENNEDY QUOTE) We are at a crossroads… not the one Woody Allen facetiously described, but the one John F. Kennedy referred to in his inaugural address. With many of the world's resources already stretched precariously thin by the juggernaut of population growth, we have entered a make-or-break era in which the die will be cast for the next millennium.

The effort to survive the gathering storm will not only call for technological solutions, it will also raise questions about the ways in which we use the technology we create. Even the most dyed-in-the-wool technological optimist is having to blink at the pace of change and the reach of some of the new technologies.

For example, we are already seeing a digital divide separating the world into the "technological haves" versus the "technological have-nots." If the "technological haves" use the interface of biotechnology and computing technology to enhance their intelligence and prolong their lives, what does that mean for the "technological have-nots"? Will they be doomed to extinction? Will they strike out at those who have technology?

As society has become more complex, we have already reached the point of using the capabilities of intelligent machines to shape the way we respond to things. As the decisions have become more difficult we have begun to rely on machines that can analyze complex systems much easier and faster than humans can. Will we inadvertently drift too far in this direction and come to the place where we find machines making the decisions for us, before we realize what has happened and

can no longer take back control of the decision-making process? Will Hal win in the next version of the story?

(SLIDE #34: BILL JOY QUOTE) For their part, scientists, rapt in the delight of discovery, tend to get caught up in the vortex of their own progress, and are pulled along without taking time to consider where it is they are going. As for the rest of us, scientific breakthroughs have become so frequent that we accept them as matter of course and do not look at them too closely.

The speed at which technology is changing means that if we do not make a deliberate effort to assess its ramifications, we may not always see the dangers approaching until the fail-safe point is upon us or even past.

A growing number of scientists and engineers at Georgia Tech and around the country feel it is time to begin asking larger questions about technology and how it will affect us in the long run. We are in the planning stages for a center that will look at technology in the broader picture of social change and ethical values. We probably have about 30 years for the human species to develop answers to these issues. After that our human-spawned competition may have the edge.

(SLIDE #35: WORLD) The first step toward achievement is acknowledging the challenge, and this forum provides an important opportunity for us to do that. I thank you for inviting me to open the discussion on the future of technology, and I look forward to continuing it tonight and in the future.